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Graduate- and undergraduate-student perceptions of and preferences for teaching practices in STEM classrooms

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Abstract

Despite positive evidence for active learning (AL), lecturing dominates science, technology, engineering, and mathematics (STEM) higher education. Though instructors acknowledge AL to be valuable, many resist implementing AL techniques, citing an array of barriers including a perceived lack of student buy-in. However, few studies have explored student perceptions of specific AL teaching practices, particularly the perceptions of graduate students. We explored student-reported instructional strategies and student perceptions of and preferences for a variety of teaching practices in graduate and undergraduate classrooms across three STEM colleges at a large, public, research university. We found that both graduate and undergraduate students desired more time for AL and wanted less lecturing than they were currently experiencing. However, there was no single universally desired or undesired teaching practice, suggesting that a variety of AL teaching practices should be employed in both graduate and undergraduate courses.

Introduction

Science, technology, engineering, and math (STEM) higher education is undergoing rapid change, driven by an increase in the number and diversity of students, digitalization and globalization, and shifting demands from policymakers and society at large (Brewer & Smith, 2011; Graham et al., 2013; Olson & Riordan, 2012; Shin & Harman, 2009). Simultaneously, research into evidence-based pedagogy has revealed that traditional, lecture-based teaching is not only ineffective overall, but disproportionately disadvantages women, first-generation students, and students from underrepresented minority groups (Ballen et al., 2017; Haak et al., 2008; Theobald et al., 2020). As a result, instructors are encouraged to teach using evidence-based approaches that increase student motivation, collaboration, and metacognition, all of which influence students' learning and course performance in STEM (Council, 2003; Glynn et al., 2011; Tanner, 2013). These challenges and expectations directly impact instructors, who may lack the time, funds, and extrinsic motivators to think deeply and scientifically about teaching (Gormally et al., 2016; Miller & Metz, 2014; Patrick et al., 2016).

Evidence-based teaching is an umbrella term that includes active learning and other teaching practices shown to positively impact student learning (Felder et al., 2000; Owens et al., 2017). Active learning is itself a catch-all phrase, derived from constructivism, a learning theory that proposes that students learn by constructing their own knowledge (Freeman et al., 2014). Within a constructivist framework, learning is an active process and builds on experience, instruction, and the foundations of prior knowledge (Bransford & Schwartz, 1999; Prince, 2004). In practice, active learning can include small-group discussion (Tanner, 2013), classroom-response systems (e.g., "clickers"; Cotner et al., 2008), one-minute papers and worksheets, completed individually or in groups, and collaborative group work (e.g., via case-studies, problem-based learning, or process-oriented guided inquiry learning [POGIL] (Eberlein et al., 2008). Through engagement

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in active learning practices, students remain an integral part of the learning process by building meaning and constructing knowledge (Prince, 2004).

Despite the evidence in support of active learning (Freeman et al., 2014), lecturing remains a pervasive feature of STEM teaching (Akiha et al., 2018; Stains et al., 2018). Some faculty may choose to lecture because they are not convinced that active learning is effective (Michael, 2007; Silverthorn et al., 2006). Other instructors value active learning (Patrick et al., 2016), but refrain from integrating active learning techniques, citing an array of barriers including the time needed to prepare "activities" (Brownell & Tanner, 2012), lack of training in effective teaching techniques, lack of time for content coverage (or, the loss of lecture time), perceived lack of student buy-in (Cavanagh et al., 2016; Deslauriers et al., 2019; Owens et al., 2017), or the concern that their classes are prohibitively large for active learning (Patrick et al., 2016; Silverthorn et al., 2006). In this work, we focus on one of these perceived barriers—a lack of student buy-in to active learning pedagogies.

A significant predictor of active learning implementation and engagement with teaching practices is the faculty and students' buy-in. (Cavanagh et al., 2016; Madson et al., 2017). Faculty often fear student resistance to active learning (Seidel & Tanner, 2013; Silverthorn et al., 2006), impacting the classroom environment and their evaluations by students (Henderson et al., 2018). Although these evaluations are flawed (Carpenter et al., 2020; Stroebe, 2020; Uttl et al., 2017; Wang & Williamson, 2020) they remain meaningful to the faculty for merit pay, promotion, and tenure. We also recognize that student *preferences* don't always mirror the practices that lead to the most learning gains (Deslauriers et al., 2019) which is also reflected by work at our own institution (Cotner et al., 2008; Walker et al., 2008). Perceived student resistance can be lowered with evidence, and previous studies have examined student perceptions of active learning in individual undergraduates (Bransford & Schwartz, 1999; Brazeal et al., 2016; Brigati, 2018; Brown et al., 2017; Cavanagh et al., 2016, 2018; Cooper et al., 2017; England et al., 2017; Machemer & Crawford, 2007; Mcmillan et al., 2018; Owens et al., 2017; Patrick et al., 2016; Smith & Cardaciotto, 2011) or graduate (Jones et al., 2010; Lopez & Gross, 2008; Miller & Metz, 2014; Tune et al., 2013) courses. Although the opinions of individual students may differ, as a whole, both graduate and undergraduate students in individual STEM courses reported neutral through very positive perceptions of and preference for active learning teaching practices (Patrick, 2020). These studies provide valuable insight into how students view these teaching practices. However, these were studies of specific courses, and active learning implementation was controlled by or known to the researchers. As a result, it remains unknown if the findings represent student perceptions and preferences within a broader context.

Few studies have examined student perceptions of and preferences for teaching practices across STEM disciplines, where active learning remains limited, and student resistance is often a perceived barrier (Patrick et al., 2016; Patrick et al., 2018). Patrick et al. (2016) and Patrick et al. (2018) examined student perceptions of active learning and other teaching practices among science college departments of a large research-intensive university in the southeastern United States. Using a modified survey (Miller & Metz, 2014), students were asked to estimate the amount of their science class time devoted to active learning and the amount of time students thought should be dedicated to active learning. These studies also prompted students to rank six broad teaching practice categories most effective for their learning. Compared to graduate students, undergraduates reported less active learning in their classes. Nevertheless, both groups wanted more active learning than currently experienced (Patrick, 2020; Patrick et al., 2016, 2018). These studies used broad categories of teaching practices, making it impossible to interpret student perceptions of and preferences for specific teaching practices like think-pair-shares (Kaddoura, 2013). However, we can leverage student attitudes of particular teaching practices to increase faculty willingness towards such activities. Also, gauging the perceptions of different student populations is essential to learn how active learning and other teaching practices can be generalized in different contexts (Patrick, 2020).

As we have stated above, similar works in different higher educational contexts have not explored student attitudes towards particular teaching practices. To address this gap in knowledge, we surveyed students in three STEM-focused colleges at one large university in the midwestern United States to determine their experiences and perceptions of specific teaching practices. Specifically, we compared student perceptions of the teaching strategies employed in their undergraduate and graduate-level courses to detect whether students valued different pedagogies at different stages of their education (i.e., undergraduate or graduate). We also compared the alignment between experienced and desired teaching practices in both undergraduate and graduate-level courses. Through our study, faculty and other stakeholders can be more fully informed and understand the instructional choices and student preferences throughout the STEM curriculum.

The main questions guiding this work were:

How do undergraduate and graduate students perceive the teaching practices in their curricula? Specifically, which teaching practices do undergraduate and graduate students experience and which do they prefer?

Are there notable differences in undergraduate and graduate perceptions regarding the implementation of active learning in their courses?

Theoretical framework

Active learning is a broad group of teaching practices informed by constructivism and socio-constructivism (a variant of constructivism), which view learning as an active process (Dewey, 1966). In a constructivist approach, learners internally build knowledge structures from experience, instruction, and on the foundations of prior knowledge (Bransford & Schwartz, 1999; Prince, 2004). As such, teaching practices informed by constructivism require learning to begin from a student's prior knowledge. For instance, in an undergraduate learning space, instructors can set up pre-lecture questions or clicker questions to investigate students' prior knowledge on the topic at hand. Once prior knowledge is known, it is used as the foundation to design instruction from where students begin their learning process (Handelsman et al., 2004). Building off Dewey's work, a constructivist approach, including active learning, rejects the notion that students are "empty vessels" needing teachers to fill them with knowledge. Instead, students actively engage in their own learning process (Bransford & Schwartz, 1999). By definition, active learning is "instructional activities involving students in doing things and thinking about what they are doing" (Bonwell & Eison, 1991). At one end of the active learning spectrum, it can be merely pausing lectures to allow students to clarify and organize their ideas through discussion with a neighbor. The other end of the spectrum can encompass more complex activities, including using case studies as a focal point for decision making (Brame, 2016).

In the higher education context, "active learning" is a term encompassing a diverse assortment of teaching practices in which students engage actively with the course content, instructor, and each other using various activities. Additionally, active learning practices are characterized by students involved in solving problems, reading, writing, and discussing (Prince, 2004). Overall, such methods have a greater emphasis on students' explorations of their attitudes and values than traditional ways of teaching (Bonwell & Eison, 1991). Specifically, some teaching practices with these attributes include group discussions, clicker questions, debates, and projects (Miller & Metz, 2014). These practices aim to involve students in higher-order thinking tasks, which lead to knowledge construction.

Materials and methods

Institution and study participants

Our institution is a large land-grant university in the Midwest, serving 32,000 undergraduate and 16,000 graduate students. There are three central STEM Colleges: the College of Biological Sciences (CBS), the College of Science and Engineering (CSE), and the College of Food, Agriculture, and Natural Resource Sciences (CFANS). There is a total of 27 departments in these Colleges, with an aggregate enrollment of 12,096 students at the time of survey distribution. We were interested in comparing STEM undergraduate and graduate student experiences with active learning. Accordingly, any student enrolled in a degree program in either of the three STEM Colleges was in our target population.

Survey instrument

Because we were interested in student perceptions of and preferences for specific teaching practices and active learning in general, we combined items from several existing survey instruments (DeMonbrun et al., 2017; Miller & Metz, 2014; Patrick et al., 2016). We asked all students to identify the largest STEM course they had taken in the preceding semester and to estimate the number of students enrolled. We asked this to encourage students to think about a single large-enrollment course and make the response sets more similar in the types of courses evaluated. For undergraduates, such large courses are often considered "gateways" to STEM majors and have received considerable attention from discipline-based education researchers (Barr et al., 2008; Witherspoon et al., 2019; Xie et al., 2015). For graduate students, a question on their largest course is likely to prevent them from considering a seminar or dissertation-credit course in their responses. For the identified course, we asked students how often the course instructor used specific teaching practices (Table 1). Most of the teaching practices included in the instrument were taken directly from the Student Response to Instructional Practices (StRIP) instrument (DeMonbrun et al., 2017). We modified two practices for clarity and added three known teaching practices at our institution (Table 1). For each teaching practice, students responded to the prompt: "Please indicate how often each activity was done in the largest science course you took this semester." Frequency options were: Never or almost never (0–10% of the time) (scored as 1); Seldom (11–30% of the time) (scored as 2); Sometimes (31–50% of the time) (scored as 3); Often (51–70% of the time) (scored as 4); Very often (71–100% of the time) (scored as 5). These options differed from those in the original StRIP to better align with the question about how much class time they think is and should be devoted to active learning included in our study. For each teaching practice, students were asked, "How often would you like to do each activity in an ideal course you would take as a student?" Response options were: Much less (scored as 1); Slightly less (scored as 2); About the same (scored as 3); Slightly more (scored as 4); Much more (scored as 5).

Table 1 Teaching practices included in the survey instrument and their source. Students were asked how often each teaching practice occurred in their largest STEM course and how often they would like each teaching practice to occur

Question number	Teaching practice	Source
Q1	Listen to the instructor lecture during class	StRIP
Q2	Brainstorm different possible solutions to a given problem	StRIP
Q3	Find additional information not provided by the instructor to complete assignments	StRIP
Q4	Work in assigned groups to complete homework or other projects	StRIP
Q5	Make individual presentations to the class	StRIP
Q6	Be graded on class participation	StRIP
Q7	Study course content with classmates outside of class	StRIP
Q8	Assume responsibility for learning material on own	StRIP
Q9	Discuss concepts with classmates during class	StRIP
Q10	Get most of the information needed to solve the homework directly from the instructor	StRIP
Q11	Be graded based on the performance of a group	StRIP
Q12	Preview concepts before class by reading, watching videos, etc.	StRIP
Q13	Solve problems in a group during class	StRIP
Q14	Solve problems individually during class	StRIP
Q15	Verbally answer questions posed by the instructor during class	Modified from StRIP
Q16	Verbally answer questions posed by the instructor during class after consulting with a class mate (think-pair-share)	Current work
Q17	Answer questions posed by the instructor during class using a student response system (clickers, TopHat, etc)	Current work
Q18	Answer questions posed by the instructor during class using a student response system (clickers, TopHat, etc) after consulting with a class mate (think-pair-share)	Current work
Q19	Ask the instructor questions during class	StRIP
Q20	Take initiative for identifying what is necessary to know	Modified from StRIP
Q21	Watch the instructor demonstrate how to solve problems	StRIP
Q22	Solve problems that have more than one correct answer	StRIP
Q23	Do hands-on group activities during class	StRIP

We also provided the students with a definition of active learning (Miller & Metz, 2014). After reading the definition, students estimated the percentage of class time typically devoted to active learning and how much time they think *should* be devoted via an open-ended response. Students also reflected on their experiences with active learning: "Please describe your experiences with active learning in the classroom." Finally, we asked students to report their status (graduate or undergraduate).

Our study design and survey instrument were approved by our the University of Minnesota's IRB (approval #STUDY00002261).

Survey distribution

During the Spring 2018 semester, we contacted college administrators to obtain lists of current graduate and undergraduate students enrolled in the STEM colleges. We used the Qualtrics platform to distribute the survey and collect responses. We offered the first 100 respondents a $5 coffee card as an incentive to complete the survey. The survey was open for a total of 2 weeks. Two reminders were sent to students who had not yet completed the survey–1 week and 1 day prior to the close of the survey.

Data analysis-quantitative

Responses were downloaded to Microsoft Excel from Qualtrics and de-identified by a researcher not otherwise affiliated with this project. We removed incomplete deidentified responses or those reported by individuals under the age of 18. Graduate and undergraduate student responses were analyzed separately. Significant differences between graduate and undergraduate students for activities desired and experienced were determined using the Mann-Whitney U test. The Mann Whitney test is most appropriate for ordinal data that deviates from a normal distribution (MacFarland et al., 2016). All data were analyzed using *Sigma plot 14.0*, the ggplot2 package for R, and RAWGraphs (Mauri et al., 2017; Team, 2013; Wickham, 2016).

Data analysis-qualitative

Seven hundred sixty-eight students responded to the open-ended prompt, “Please describe your experiences with active learning in the classroom.” Two coders, trained in in-vivo coding (Saldaña, 2009), read student responses, unaware of whether a graduate- or undergraduate-level student wrote the response. In an initial meeting, the coders identified consensus categories; afterward, they identified the following emergent categories (along with associate sub-categories) from the student responses: Positive About Active Learning (active learning a) makes the class engaging, b) is beneficial, c) helps with content retention, d) builds community and e) prepares for real-world work environment); Negative About Active Learning (active learning a) limits individual thinking and learning, b) professor does not implement active learning approach correctly, c) should only be used in particular fields and d) current active-learning methods are a “waste of time”); and Constructive (active learning a) works when people are prepared to collaborate b) only works in smaller classes, c) effective active learning is desirable, and d) works well when supplemented with other methods. Upon the generation of a sub-categories codebook, each coder coded the same randomly selected 10% of the comments to establish interrater reliability. Cohen’s Kappa (κ) is a robust statistical approach for testing reliability while accounting for chance agreement between two raters. The raters received a $\kappa = 0.87$, considered a *strong* agreement on the Kappa scale (Cohen, 1960). Once reliability was established, we divided the remaining responses among the two coders. When the coding was completed, the sub-categories were tallied, and the responses were decoded to allow for comparison between graduate and undergraduate student responses.

Results and discussion

Participant attributes

In total, 1274 undergraduate ($n = 1113$) and graduate ($n = 161$) students completed the survey (Table 2). Nearly equal numbers of first-year, second-year, third-year, and senior undergraduates responded, which together greatly outnumbered the graduate respondents. Respondents who identified as female outnumbered respondents who identified as male. The mean class sizes reported by graduate and undergraduate students were 39 and 178 students, respectively, for their largest science course.

Teaching and learning practices experienced by students

Of the 23 teaching practices included in our survey, all students identified instructor lecturing (Q1) as the most common teaching practice in their courses, which occurred, on average, *very often* (Fig. 1a). This finding is consistent with other studies, which demonstrate that STEM classrooms are dominated by teacher-centered pedagogy with lecturing as the primary mode of instruction (Akiha et al., 2018; Stains et al., 2018). Graduate and undergraduate students also identified four other practices that, on average, happened *often* in their largest STEM courses: assuming responsibility for learning the material (Q8), getting homework information from the instructor (Q10), taking the initiative in deciding what is necessary to know (Q20), and watching the instructor demonstrate how to solve problems (Q21; Fig. 1a). These results suggest that all students experienced teaching and learning practices that were dominated by direct faculty-to-student, teacher-centered instruction.

Table 2 Student Attributes

Student status	*n*
Total	1274
Graduate	161
Undergraduate	1113
Freshman	268
Sophomore	259
Junior	272
Senior	247
Other	67
Gender	*n*
Female	697
Male	427
Other	14
No Answer	136

The teaching practices experienced by students *least often* were all active learning techniques, but these differed between undergraduate and graduate students. Undergraduates identified individual student presentations (Q5) as the least performed instructional practice (Fig. 1b). This finding is not surprising due to time constraints in large-enrollment courses. Teaching activities that entail direct feedback from instructors were also infrequently experienced. For example, students seldom experienced answering questions using student response systems—either directly or following a consultation with a classmate (Q17 and Q18; Fig. 1b). However, studies have demonstrated that students using student response systems in large classrooms are more engaged than those that do not use clickers (e.g., Mayer et al., 2008). Moreover, students retain more material on exam units covered in lessons that incorporate clicker activities (Crossgrove & Curran, 2008). Hands-on group activities and answering questions posed by the instructor were also uncommon practices in undergraduate courses (Q23 and Q15; Fig. 1b).

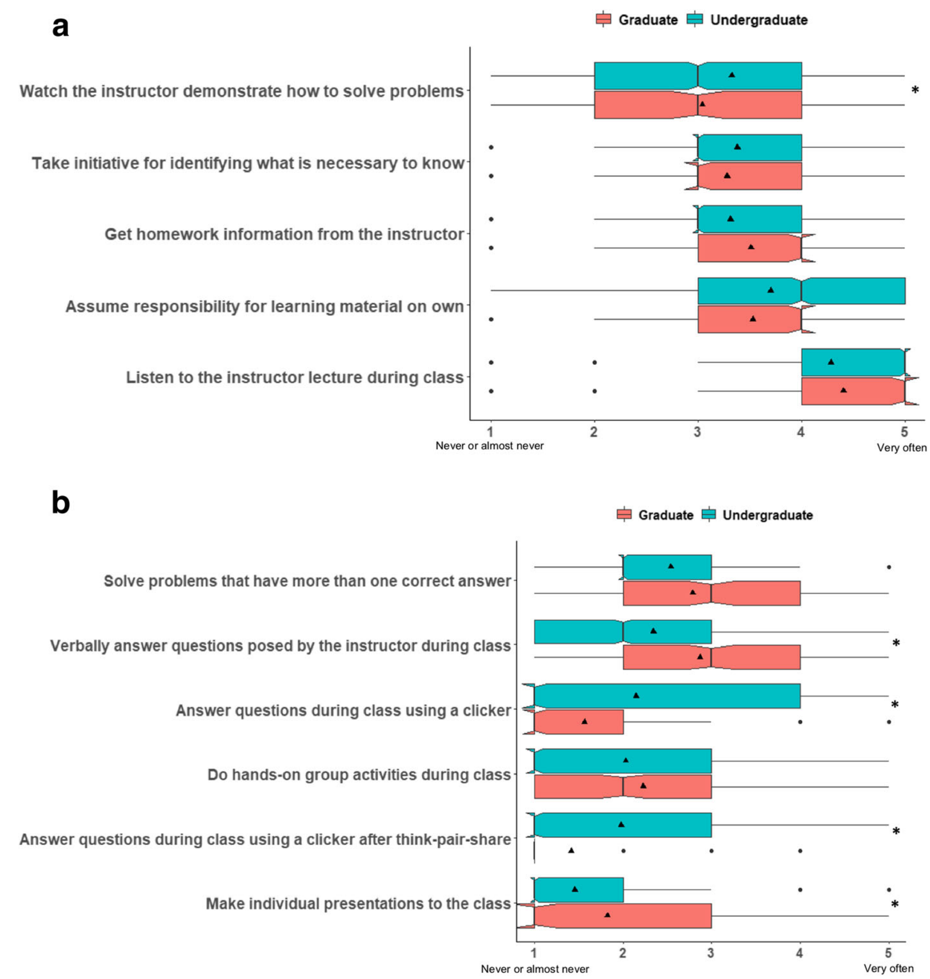

Fig. 1 Box and whisker plots of the most and least common instructional practices reported by graduate ($n = 161$) and undergraduate ($n = 1113$) students in STEM classrooms. **a** Most frequently experienced activities, and **b** Least frequently experienced activities. Triangles indicate mean values. *indicates p-values $\le$ 0.05. Activities displayed are the five most and least desired. A reported sixth activity in panel b reflects the ranking misalignment between graduate and undergraduate students

Graduate students reported the use of student response systems (i.e. Top Hat, clickers), both in isolation or following consultation with a classmate (think-pair-share), as the least common activities experienced in their courses (Q17 and Q18; Fig. 1b). We suspect that graduate-level instructors may be less inclined to use a classroom response system given the smaller class sizes of such courses. Giving individual presentations (Q5), answering questions verbally in the classroom (Q14), and solving problems that have more than one correct answer (Q22) were also infrequent in graduate courses (Fig. 1b).

Our findings for how often all 23 teaching practices were experienced by students in our sample can be found in the lower panel of Fig. S1.

Teaching practices preferred by students

Undergraduate and graduate students desire significantly more class time for active learning pedagogies than they are experiencing (Fig. 2). On average, undergraduate students reported 31% of class time was *currently* being devoted to active learning and that 36% of class time *should be* devoted to active learning. Graduate students reported that significantly less class time, 25%, was *currently* devoted to active learning and that 36% of class time *should be* devoted to active learning (Fig. 2). These findings suggest that both groups of students want more active learning in their classrooms than currently experienced and desire a similar amount (~ 36% of class time) dedicated to active learning. Overall, most students have positive perceptions of active learning and perceive the benefits and/or utility of these practices. However, both student populations still valued listening to lecture (Fig. 4).

Specifically, undergraduate students preferred instructional practices that involve peer-assisted learning and direct feedback from instructors (Fig. 3a). For undergraduate students, the top five most desired teaching

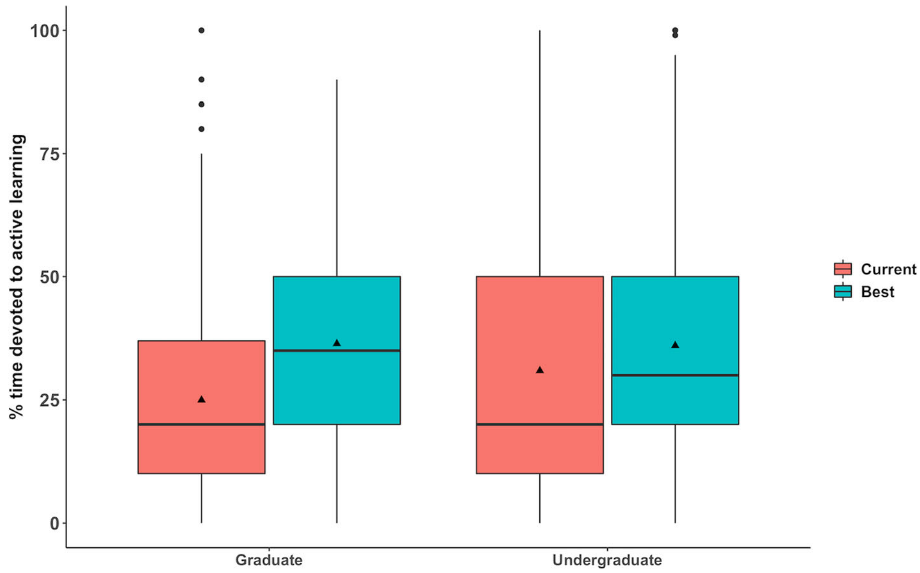

Fig. 2 Box and whisker plots of the percent of class time graduate and undergraduate students think is currently ("Current") and should be ("Best") devoted to active learning. Students were provided a definition of active learning (Miller & Metz, 2014) and via an open-ended response, asked to estimate the amount of class time typically devoted to active learning and how much time they think *should* be devoted to active learning. Triangles indicate mean values. *indicates p-values ≤ 0.05

practices were watching the instructor demonstrate how to solve problems (Q21), getting homework help directly from the instructor (Q10), brainstorming different solutions (Q2), studying course content with classmates outside of class (Q7), and asking the instructor questions during class (Q19). These preferences reflect that students value a variety of teaching strategies in their classroom. For instance, students' understanding of conceptual questions increases after discussion with classmates regardless of students' initial knowledge of the answer (Smith et al., 2009). Undergraduate students also valued peer-assisted learning *outside* of the classroom and discussing course concepts with peers. These meaningful peer interactions outside of the classroom lead to gains in students' cognitive development (Jones et al., 2008) Similarly, graduate students' most desired forms of instruction included watching the instructor demonstrate how to solve problems (Q21), brainstorming solutions (Q2), asking the instructor questions during class (Q19), discussing concepts with classmates (Q9), and getting help from the instructor with their homework (Q10; Fig. 3a).

For undergraduate students, the five least desired forms of instruction were finding additional information not provided by the instructor (Q3), being graded based on the performance of a group (Q11), assuming individual responsibility for the learning material (Q8), making individual presentations to the class (Q5), and being graded on class participation (Q6; Fig. 3b). The least desired instructional practices were similar for graduate students: being graded on group performance (Q11) or class participation (Q6), finding additional information not provided by the instructor to complete assignments (Q3), working in assigned groups (Q4), and listening to the instructor lecture during class (Q1; Fig. 3b). Other studies have also found that undergraduate students felt unprepared to evaluate the value and importance of information and the work of others (Owens et al., 2017) and were often resistant to working collaboratively when their grades were on the line (Machemer & Crawford, 2007; Owens et al., 2017; Patrick et al., 2016). It is noteworthy that graduate students also disliked these teaching practices because in many ways these are vital elements of modern scientific practice. Using transparent grading rubrics, making expectations clear, and using best practices when assigning group work may help to increase student buy-in. The results for all 23 teaching practices can be found in the upper panel of Fig. S1. Although the mean values vary, the median desired level of each teaching practice mostly centered around *about the same*.

The summary statistics above highlight the trends in the data, but they also mask important variation that lends insights into student perceptions of active learning. Figure 4 illustrates the variation in responses for three example teaching strategies (responses for the remaining teaching strategies can be found in S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20 and S21 Figs). As reflected in Fig. 2, most students experienced lecturing (Q1) the majority of the time.

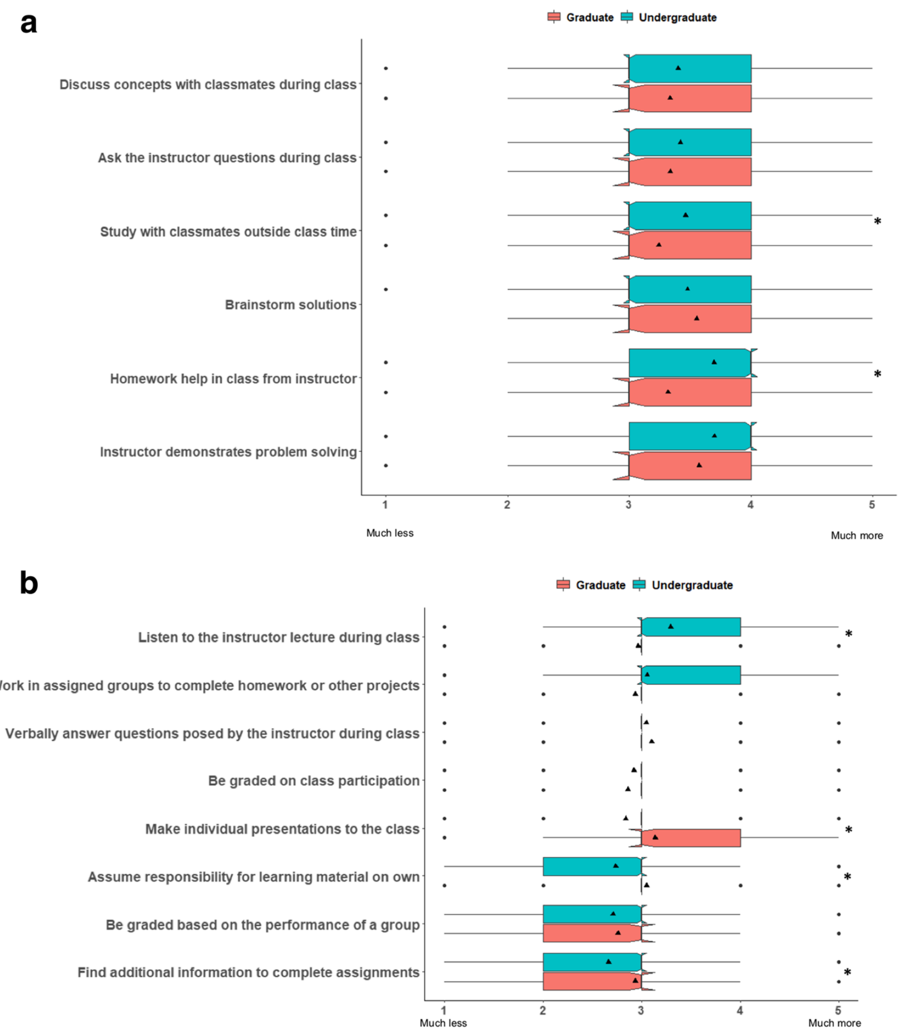

Fig. 3 Box and whisker plots of the most and least desired instructional practices reported by graduate ($n = 161$) and undergraduate ($n = 1113$) students in STEM classrooms. **a** Most preferred activities **b** Least preferred activities. Triangles indicate mean values. *indicates *p*-values ≤ 0.05. Activities displayed are the top five most and least desired. Reported additional activities reflect the ranking misalignment between graduate and undergraduate students

Very few students reported experiencing courses in which 70% or less of the time was devoted to lecture. Overall, students desired lecture about as much as they were currently getting (Fig. 4). This interest in lecture may seem counter to the documented benefits of active learning teaching practices (Freeman et al., 2014), however, a deeper look at the data gives the story more nuance.

For example, approximately equal numbers of students reported that discussing concepts with classmates during class (Q9) happened *never* or *almost never* through *very often* (Fig. 4). Despite a median desired value of *same* (Fig. 3a), this particular active learning teaching practice was desired more often by a substantial number of students; very few students who *never or almost never* experienced this practice wanted less of it (Fig. 4). Answering questions posed by the instructor using a student response system after consulting with a classmate (Q18) was experienced *never* or *almost never* by the vast majority of the students in our sample (Fig. 4), and while the majority of students desired this teaching practice about the same amount, a sizeable proportion wanted more and fewer still wanted less (Fig. 4). Similar trends are evident for most of the remaining 20 teaching practices (S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20 and S21 Figs).

The data above demonstrate that while many students value lecture, they also desire active learning practices, suggesting the students in our study "buy-in" to active learning—that is, they perceive it as valuable. However, we also found that no single teaching practice was universally desired – or not desired – suggesting to us that

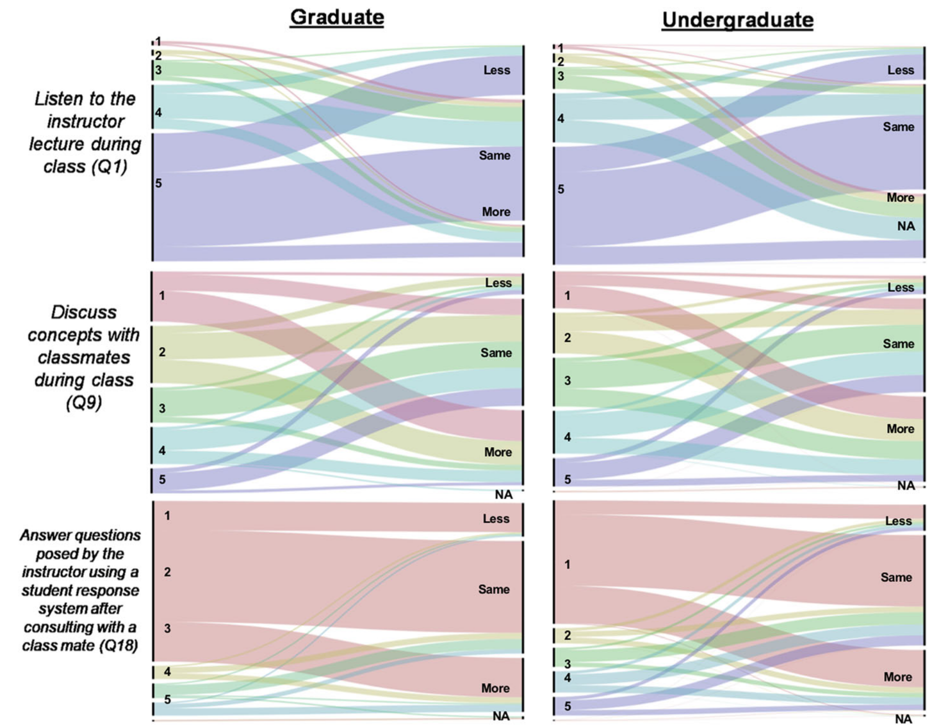

Fig. 4 Alluvial plots of how often students reported experiencing a teaching practice and how much that teaching practice is desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left) and the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia," or lines between columns, indicate how often students reported experiencing a teaching practice (left side of each graph) and how much that teaching practice was desired (right side of each graph) and are proportional to the number of respondents. NA = respondents who did not respond to a particular question; 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time). Less = a combination of Much less and Slightly less desired; Same = About the same; More = a combination of Slightly more and Much more desired

educators should employ a variety of active learning teaching practices in graduate and undergraduate classrooms alike.

Student perceptions of active learning based on free-response items

Seven hundred sixty-eight students answered the prompt, "Please describe your experiences with active learning in the classroom." We analyzed all the responses, which include 104 graduate and 664 undergraduate student responses. We identified these responses by the categories and subcategories described in the methods. Sample comments are included, along with the total number of responses in each category, in Table 4. Each student response was coded, line by line. As a result, some responses were a combination of values under the three categories. For example, 64% (422/664) of the undergraduate responses were in a single category, 29% (193/664) in two and 7% (49/664) were in three categories. Likewise, 72% (75/104) of graduate responses were in a single category, 21% (22/104) in two and ~ 7% (7/104) were in three categories. For both graduate and undergraduate students, most responses were in a single category. In Table 3, we provide an example of a response coded for more than a single category.

The three overarching categories are Positive (in which the student is voicing an appreciation for active learning); Negative (in which the student is unambiguously negative); and Constructive (in which the student suggests the conditions under which active learning can be useful). We identified overwhelmingly positive codes for both graduate and undergraduate student responses, followed by negative and constructive codes (Table 5).

Five Positive subcategories emerged—active learning a) makes the class engaging, b) is beneficial, c) helps with content retention, d) builds community and e) prepares for real-world work environment (Table 4). Over half of both the graduate (62/104) and the undergraduate (380/669) students expressed a positive impression of active learning (subcategory "active learning is beneficial") (Table 4). One graduate student reported, "I felt I got to use the material rather than passively take it in, and I got to know my classmates better, which made coming

Table 3 Student Response Coding Template/Example

Please describe your experiences with active learning in the classroom:	Categories	Subcategories
I currently have my biology class in an active learning classroom and one professor knows how to use the active learning classroom and it really benefits all the students, but the other doesn't know how to use it properly and I learn less from him than I do in a normal lecture without active learning.	**Positive:**	1. Active Learning is Beneficial
	Negative:	1. Professor does not implement active learning approach correctly

to class much more enjoyable." An undergraduate said, "Active learning is a very effective method to get students to really understand their curriculum since questions are encouraged as well as predictions/guesses." Many of the responses spoke to a general appreciation for active learning. However some responses included disclaimers such as, "I think a traditional lecture has its place explaining basic concepts and helping students get comfortable with the material, but activities can help engage and apply the material" (undergraduate student) and "Sometimes [active learning] is effective, and sometimes it is patronizing" (graduate student).

Four Negative sub-categories were identified—(a) active learning limits individual thinking and learning, b) professor does not implement active learning approaches correctly, c) active learning should only be used in certain fields, d) current active learning methods are a "waste of time" (Table 4). In these negative subcategories, the largest number of comments belonged to "current active-learning methods are a 'waste of time'"—for both graduate ($n = 14$ responses) and undergraduate ($n = 98$ responses) students (Table 4). According to one graduate student, "Some [professors] are awesome at using active learning for its positive, intended uses while others are totally off-base and waste class time without any benefit to the students." Similarly, an undergraduate student opined, "The material has to be dumbed down so any idiot can figure it out and working in groups means you work at the slowest pace of anyone there. It also doesn't help that there's barely any time for the professor to talk about a new concept."

Lastly, four Constructive sub-categories emerged—(a) active learning works when people are prepared to collaborate, b) active learning only works in smaller classes, c) effective active learning is desirable, d) active learning works well when supplementing other methods (Table 4). The most comments in this domain belong to sub-category, "Effective active learning is desired.", evident in 116 undergraduate and 18 graduate student responses (Table 4). Student suggestions varied, from "Sometimes they [active learning] feel [s] like a hassle. Good active learning should be integrated smoothly, but with a clear goal in mind" (undergraduate), and "Usually there is some lecture portion, then the active learning with worksheets or games, etc. What is most vital is that we actually have the information to be able to do the activity before we do the activity. I found it happens a lot where we have no idea what we are doing or the instructors have given no examples so we sit and play with our thumbs because we haven't learned anything. Learning first. Activities next to reinforce concepts and maybe expand upon them" (undergraduate), to "it's helpful when it is done correctly. sometimes it's more distracting than helpful" (graduate), and "Often spent at least half of lecture time going over a paper in groups. Mostly effective for learning the paper if students actually read it, but there was no system in place for ensuring accountability, leading to some group sessions suffering. Also, while a lot was learned during these times, what was discussed in class did not usually help for questions on the exams" (graduate).

Notably, apparent differences between the two populations were not evident. Specifically, the themes that were the most common for undergraduate students were the most common for graduate students as well (Table 4).

Are there notable differences between undergraduate and graduate students in the amount or type of active learning experienced or desired?

Undergraduate and graduate students reported similar patterns in the most common instructional activities (Fig. 1a). Some differences emerged in the least common teaching practices (indicated by * in Fig. 1b), the most and least desired teaching practices (* in Fig. 3), and how much time was currently devoted to active learning (* in Fig. 2). While all students rarely experienced individual presentations (Q5), such practices occurred significantly more often in graduate than in undergraduate courses. Undergraduate students also reported significantly fewer opportunities for verbally answering questions in class (Q15) compared to graduate courses. For graduate classes, the use of student response systems (i.e., Top Hat, clickers), either independently (Q17) or following consultation with a classmate (think-pair-share; Q18), was significantly less common than in undergraduate classrooms (Fig. 1b). Overall, graduate students reported slightly, though significantly, less class time devoted to active learning practices than their undergraduate counterparts (Fig. 2).

Although both groups of students wanted more direct engagement with instructors, undergraduates had a greater desire for such activities than their graduate counterparts. (Figs. 3a and 4; S9,17 Figs). Specifically,

Table 4 Categories (Positive, Negative, and Constructive) and subcategories identified in student responses to the prompt "Please describe your experiences with active learning in the classroom." Number of responses in each subcategory are included in parentheses after a sample comment

Categories	Undergraduate comments	Graduate comments
Positive		
Active learning makes the class engaging	I personally prefer active learning in the classroom. It's difficult for me to focus during long lectures so having an activity to direct my attention to helps me better apply the material I have learned and understand what I need improvement on. (85)	Active learning broke the class into small groups to work on a problem together. I felt I got to use the material rather than passively take it in … (14)
Active learning is beneficial	In a previous math class, there was a significant amount of active learning, with very engaging exercises and significant in-class participation. Although I was off-put at first by how different the class was at first, I feel now as though I retained and ultimately was much more successful in that course than in others due to the number of activities we went through. (380)	Even graduate students benefit from active learning so I wish it was used more in these higher-level courses! (62)
Active learning helps with content retention	When implemented correctly (not just clicker-question based), I find active learning to be helpful and good for long term information retention. (88)	Active learning classrooms are harder but I do retain and learn the information much better and still recall things years later. (16)
Active learning builds community	[Active learning] can be a great way to connect with other students and build community. (56)	[Through active learning], I got to know my classmates better, which made coming to class much more enjoyable. (7)
Active learning helps with real world work environment	I do not necessarily enjoy active learning and I often hate working in groups, but I understand that it is an important skill to learn and I understand why active learning is important. (9)	Active learning is essential as it helps to understand the concepts, retention of information and how to use the acquired knowledge in real life situation. (1)
Negative		
Active learning limits individual thinking and learning	Active learning doesn't help me, personally, in the classroom. I learn best by watching, taking notes, and reviewing and quizzing myself on the material on my own time. I like things like clickers, to make sure I understand a concept, but otherwise, non-lecture classrooms keep me from focusing on what I need to learn. (75)	I am not a person that functions well in group settings. I learn much better by figuring out the problem on my own and discussing questions at my own pace with the lecturer. (7)
Professor does not teach using an active-learning approach correctly	Sometimes it's helpful, sometimes it's not. It really depends on the engagement of the professor with the students and the discussions between group members. (117)	We are paying a lot of money for the expertise of the instructors and their presentation of the information through a traditional lecture. Active learning is guided in concept. But in practice it is mostly the students teaching themselves. And if I wanted that, to teach myself, or learn from other clueless students, I either wouldn't pay this much tuition or I wouldn't go to class. (10)
Active learning should only be used in certain fields	In the introductory courses, I found active learning to be a great way to learn concepts through practice. However, while I have enjoyed its usage as a teaching method, I feel that active learning may not be the best teaching/learning strategy for every course. (25)	I feel as though active learning is appropriate for some classes, but not in others. Sometimes I understand lecture material better when it is simply presented by the teacher, and other times active learning is necessary to better understand concepts. I think it really depends on the course. (5)
Current active-learning methods are a "waste of time"	Active learning is so terrible. [Name of College] thinks it is the best thing in the universe, but there really is no benefit besides me hating my group. also, that basically means the professors don't actually have to teach, which means no learning is done besides busy work. (98)	Once you get to high-level (graduate-level) courses, these [active learning techniques] become a waste of time. You no longer need to "trick" highly motivated PhD students into learning. (14)
Constructive		
Active learning works when people are prepared to collaborate	if a professor is not prepared well, it does not go well. If other students are not participating, it does not go well. (50)	In general, however, the best types of active learning for me are those that require me to work with the material independently (problem sets, games, written reflections, etc.), and not necessarily debates or discussions. However, this is mostly because I can't rely on my peers to have done enough homework or reading to maintain a valuable debate. (16)
Active learning only works in smaller classes.	I have enjoyed the use of active learning in all my science classes especially the smaller classes. In my largest class it did feel like more of a way to track attendance and get	I do NOT like activities for the sole purpose of having 'active learning...The active learning I did enjoy occurred in small classes, when either questions were encouraged

Table 4 Categories (Positive, Negative, and Constructive) and subcategories identified in student responses to the prompt "Please describe your experiences with active learning in the classroom." Number of responses in each subcategory are included in parentheses after a sample comment *(Continued)*

Categories	Undergraduate comments	Graduate comments
	points than to actually learn the material. (16)	during lectures or we had to solve cases as a class with the professor as a resource. (3)
Effective active learning is desirable	I don't like how active learning is done currently in class, but I think the idea has potential. If it didn't involve so much busy work or multitasking, I would love it a lot more. Additionally, I don't think active learning should replace lectures, but instead work alongside them. (116)	The combination of very well-presented thorough material and explanations in lectures with a couple minutes (i.e. short activities) to work with the concepts/material independently was much, much, much more useful and helped me to learn. (18)
Active learning works well when supplementing other methods	When students have to go to several lecture-based classes during the day, it is easy for them to start tuning out the teacher. If active learning were used in addition to the lecture, it would be harder for students to tune out because they have to be listening in preparation for an activity being done later in the class. Class time would be more enjoyable and engaging if some element of active learning were involved. (75)	I think active learning can be useful, however, I think the combination of traditional lectures and labs accomplishes the needs of active learning. Often, active learning activities in the classroom don't result in the creation of useful documentation that can be consulted before exams (6)

undergraduate students sought more opportunities to ask their instructors questions, and seek information directly from instructors for homework (S9, 17 Figs). Compared to graduate students, undergraduates also wanted more opportunities to study with classmates outside of class time (Fig. 3a, S7 Fig). Furthermore, there was a significant difference between undergraduate and graduate students in the desire for less lecture (Q1). Graduate students identified lecturing as one of the top five least desired activities in their classrooms and wanted significantly less than undergraduate students (Figs. 3 and 4). Finally, undergraduate students had significantly less desire for assuming responsibility for learning material on their own, listing it as one of their top five least desired classroom activities (Fig. 3b, S8 Fig).

Overall, graduate student views are similar to those of undergraduates. Both groups of students want more active learning than they are currently getting. These results are similar to recent studies examining perceptions of active learning at a different university (Patrick et al., 2016, 2018), suggesting that these findings indicate a larger trend in higher education. Additionally, graduate and undergraduate courses implemented similar teaching strategies, dominated by lecturing; in fact, significantly less class time was devoted to active learning in graduate courses compared to undergraduate courses.

Conclusions and implications

Any conclusions from these findings should be tempered with the limitations of this work. We hesitate to assign differences to our two populations beyond their status as either graduate or undergraduate students. Nonetheless, it is a reasonable assumption that graduate students are characterized by different levels of, for example, intrinsic motivation than their undergraduate counterparts. This differential motivation may lead to different expectations of or demands from their instructors. Future work, in which we attempt to align student responses with different aspects of student affect (e.g., motivation, mindset, self-efficacy) with perceptions of teaching strategies, would provide additional clarity. Further, we realize that graduate courses are likely to have a different culture than undergraduate courses, informed by factors beyond e.g., course level and class size. For example, instructors may perceive graduate students as closer to being colleagues than undergraduate students; these differences likely change in-class behaviors—of both students and instructors. It would be helpful, in follow-up work, to combine student perceptions with those of their professors.

Regardless of these and other unidentified limitations, our work contributes to the relatively small body of literature exploring the use of evidence-based, active learning techniques in undergraduate and graduate-level STEM courses. Similarly, we contribute to understanding student buy-in to active learning in the curriculum. Critically, our approach is sufficiently fine-grained to isolate which evidence-based techniques are in place and which of these techniques are desired by STEM students.

We found that graduate and undergraduate students want to experience a higher degree of active learning in their STEM classrooms than they currently experience (Fig. 2). Additionally, our open-ended responses indicate an overwhelmingly positive experience when we sought student insights on their experience with active learning (Tables 4 and 5). Though some differences were identified in the specific type of active learning preferred, both

Table 5 Summed Total of Identified Categories

	Positive	Negative	Constructive	SUM
Undergraduate	618	315	257	1190
Graduate	100	36	34	170

graduate and undergraduate populations wanted more direct feedback (i.e., formative assessment) and a chance to learn in small groups. Further, all students wanted to learn through student presentations and direct engagement with the instructor using student response systems.

On average, graduate students wanted to engage more in individual learning compared to undergraduates. Our study suggests that graduate students experienced low levels of active learning, significantly less than their undergraduate counterparts. Our findings collectively provide evidence for educators, especially those wary of student resistance to change, that students buy-in to active learning. These findings along with student input via an open-ended response suggest that most students would like to experience more active learning instructional practices in their STEM classrooms.

Our results confirm that evidence-based teaching remains relatively scarce in graduate courses. However, this part of the STEM curriculum remains insufficiently explored from the perspectives of who uses active learning, what pedagogies graduate students prefer, and whether student preferences are in line with the evidence for what works best in the classroom. Few studies are investigating active learning practices for graduate classrooms. The existing studies suggest that graduate students hold active learning perceptions similar to those of undergraduates, that is, neutral through positive (Patrick et al., 2016, 2018). For example, graduate students in a flipped classroom performed better on exams than in traditional lectures but disliked the extra time necessary to prepare for class meetings (Tune et al., 2013). Graduate students also value courses that implement a variety of active learning practices, especially when familiarized with the activities (Jones et al., 2010; Lopez & Gross, 2008; Miller & Metz, 2014). Combined with previous studies, our findings indicate a need to integrate active learning throughout all levels of the curriculum. While it may be essential to use active learning in first-year STEM courses, time, and resources should also be allocated to innovative teaching practices in upper-division and graduate-level courses.

Finally, we find no evidence that students, on average, are resistant to the implementation of techniques such as student response systems, opportunities for hands-on group work, and opportunities for direct interaction with the instructor. Instead, we identify evidence that students would prefer *more* active learning in their courses. Fortunately, instructors can implement many of these preferred active learning techniques into their existing courses with relative ease. For example, there are several excellent sources designed for educators to develop a toolkit of in-class assessment techniques such as classroom polling, short written reflections, and think-pair-share activities (Angelo & Cross, 1993; Fink, 2013; Tanner, 2013). These suggestions, combined with an awareness of student preferences, may help instructors, teetering on the brink of adoption, to leap into active learning.

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s43031-021-00035-w.

Additional file 1: Fig. S1. Box and whisker plots of all surveyed instructional practices (Q_1 through Q_23) reported by graduate (n = 161) and undergraduate (n = 1113) students in STEM classrooms. Upper row (Desired) details levels of desire for each instructional activity. Lower row (Experienced) details levels of each instructional activity reported as actually experienced in the classroom. Levels range from 1 (Never or almost never; 0–10% of the time) to 5 (Very often; 71–100% of the time). Triangles indicate mean values.

Additional file 2: Fig. S2. Alluvial plots of how often students reported experiencing the teaching practice in Q_2 ("Brainstorm different possible solutions to a given problem") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 3: Fig. S3. Alluvial plots of how often students reported experiencing the teaching practice in Q_3 ("Find additional information not provided by the instructor to complete assignments") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 4: Fig. S4. Alluvial plots of how often students reported experiencing the teaching practice in Q_4 ("Work in assigned groups to complete homework or other projects") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 5: Fig. S5. Alluvial plots of how often students reported experiencing the teaching practice in Q_5 ("Make individual presentations to the class") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 6: Fig. S6. Alluvial plots of how often students reported experiencing the teaching practice in Q_6 ("Be graded on class participation") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 7: Fig. S7. Alluvial plots of how often students reported experiencing the teaching practice in Q_7 ("Study course content with classmates outside of class") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 8: Fig. S8. Alluvial plots of how often students reported experiencing the teaching practice in Q_8 ("Assume responsibility for learning material on own") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 9: Fig. S9. Alluvial plots of how often students reported experiencing the teaching practice in Q_10 ("Get most of the information needed to solve the homework directly from the instructor") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 10: Fig. S10. Alluvial plots of how often students reported experiencing the teaching practice in Q_11 ("Be graded based on the performance of a group") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 11: Fig. S11. Alluvial plots of how often students reported experiencing the teaching practice in Q_12 ("Preview concepts before class by reading, watching videos, etc.") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column**).** The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 12: Fig. S12. Alluvial plots of how often students reported experiencing the teaching practice in Q_13 ("Solve problems in a group during class") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 13: Fig. S13. Alluvial plots of how often students reported experiencing the teaching practice in Q_14 ("Solve problems individually during class") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 14: Fig. S14. Alluvial plots of how often students reported experiencing the teaching practice in Q_15 ("Verbally answer questions posed by the instructor during class") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–

10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 15: Fig. S15. Alluvial plots of how often students reported experiencing the teaching practice in Q_16 ("Verbally answer questions posed by the instructor during class after consulting with a class mate (think-pair-share)") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 16: Fig. S16. Alluvial plots of how often students reported experiencing the teaching practice in Q_17 ("Answer questions posed by the instructor during class using a student response system (clickers, TopHat, etc)") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 17: Fig. S17. Alluvial plots of how often students reported experiencing the teaching practice in Q_19 ("Ask the instructor questions during class") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 18: Fig. S18. Alluvial plots of how often students reported experiencing the teaching practice in Q_20 ("Take initiative for identifying what is necessary to know") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 19: Fig. S19. Alluvial plots of how often students reported experiencing the teaching practice in Q_21 ("Watch the instructor demonstrate how to solve problems") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 20: Fig. S20. Alluvial plots of how often students reported experiencing the teaching practice in Q_22 ("Solve problems that have more than one correct answer") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

Additional file 21: Fig. S21. Alluvial plots of how often students reported experiencing the teaching practice in Q_23 ("Do hands-on group activities during class") and how much that teaching practice was desired for graduate students (left column) and undergraduates (right column). The vertical bars are the experienced frequency (left side of each graph) and; the vertical height of each bar is proportional to the number of respondents who chose that response. The "alluvia" or lines between columns indicate how often students reported experiencing the teaching practice (left side of each graph) and how much this teaching practice was desired (right side of each graph) and are proportional to number of respondents. NA = respondents who did not respond to a particular question. 1 = Never or almost never (0–10% of the time); 2 = Seldom (11–30% of the time); 3 = Sometimes (31–50% of the time); 4 = Often (51–70% of the time); 5 = Very often (71–100% of the time).

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Authors' contributions
SC and LP developed the survey and survey protocol. SC secured approval from the University's Institutional Review Board. NG analyzed the data. NG and LP created the data visualizations. All authors conceived of the study and participated in writing the manuscript. The author(s) read and approved the final manuscript.

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Availability of data and materials
Due to the need to protect individual student data, the datasets used for the current study are available, in de-identified, aggregate form, from the corresponding author on reasonable request.

Declaration

Competing interests
The authors declare that they have no competing interests.

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